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(54) Parallax barrier and display

(57) A parallax barrier comprises a polarisation modifying layer 20 and a polariser 21. The layer 20 has aperture regions 22 for forming the parallax barrier slits and barrier regions 24 for forming the opaque regions between the slits. The regions 22 and 24 are such that polarised light incident on the layer 20 is transmitted with orthogonal polarisations through the regions 22 and 24. For instance, the regions 24 may not affect polarisation whereas the regions 22 may rotate the polarisation by 90 degrees. The polarising sheet 24 when present has a polarisation direction 26 orthogonal to the plane of polarisation 23 of the incoming light. Light from the barrier regions 24 is thus extinguished whereas light from the slit regions 22 is transmitted so that the device operates as a parallax barrier. By removing the polarising sheet 21 or otherwise disabling it, the differences in polarisation of light from the regions 22 and 24 is not perceptible to the unaided eye. The parallax barrier may therefore be used with a spatial light modulator to form a display which is switchable between a 3D autostereoscopic mode and a 2D full resolution high brightness mode.

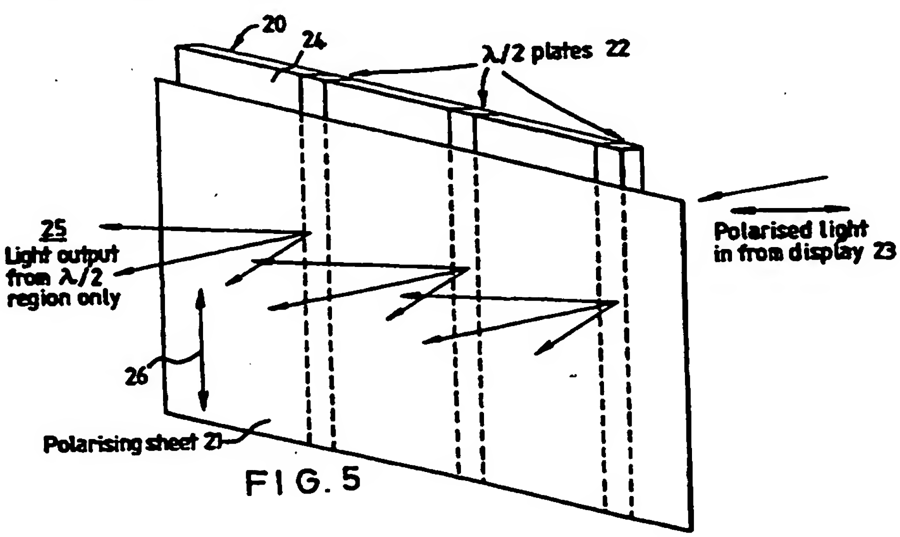
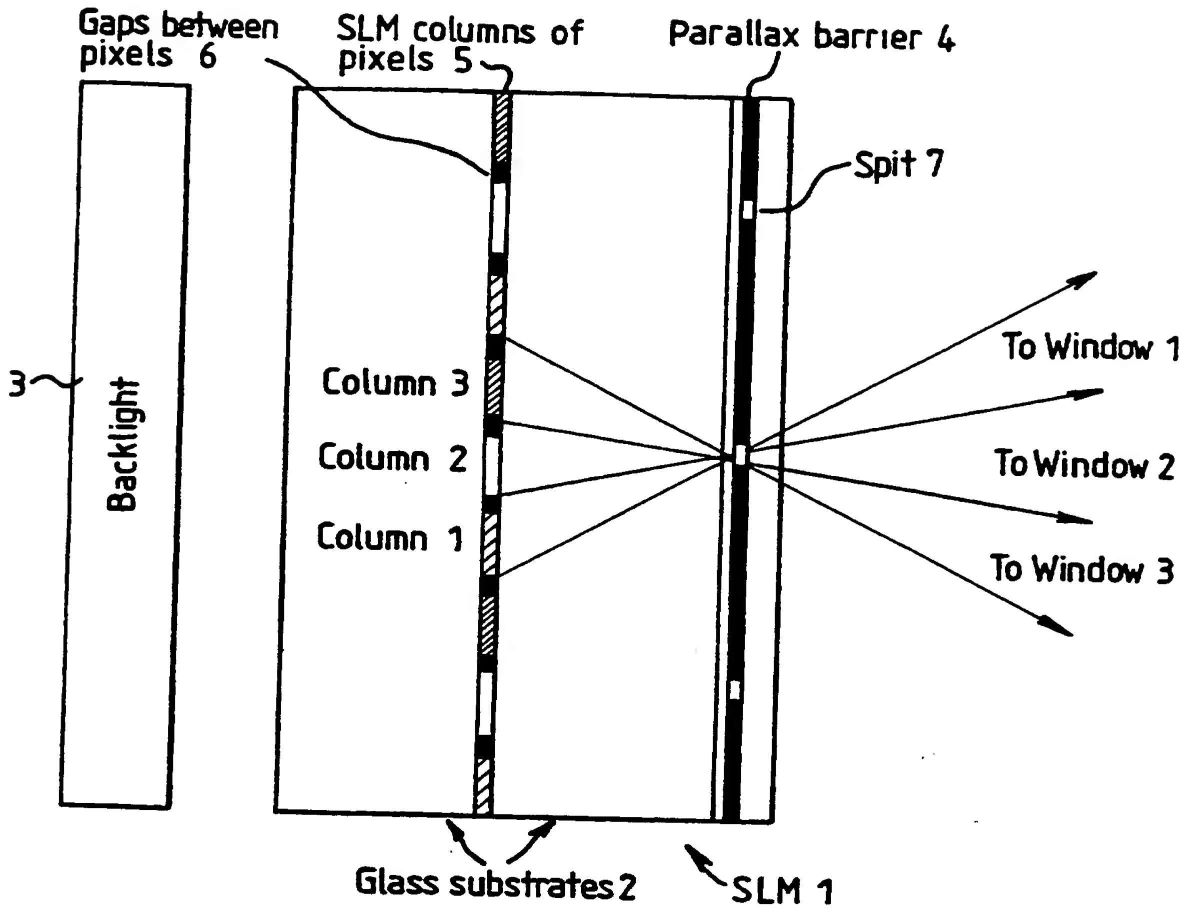


FIG. 5

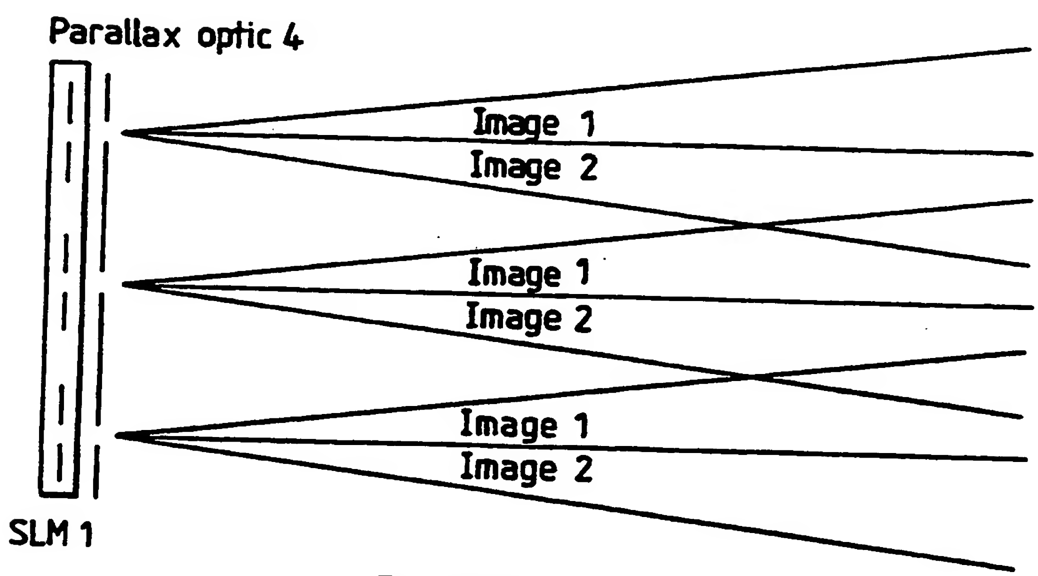
GB 2 317 295 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.



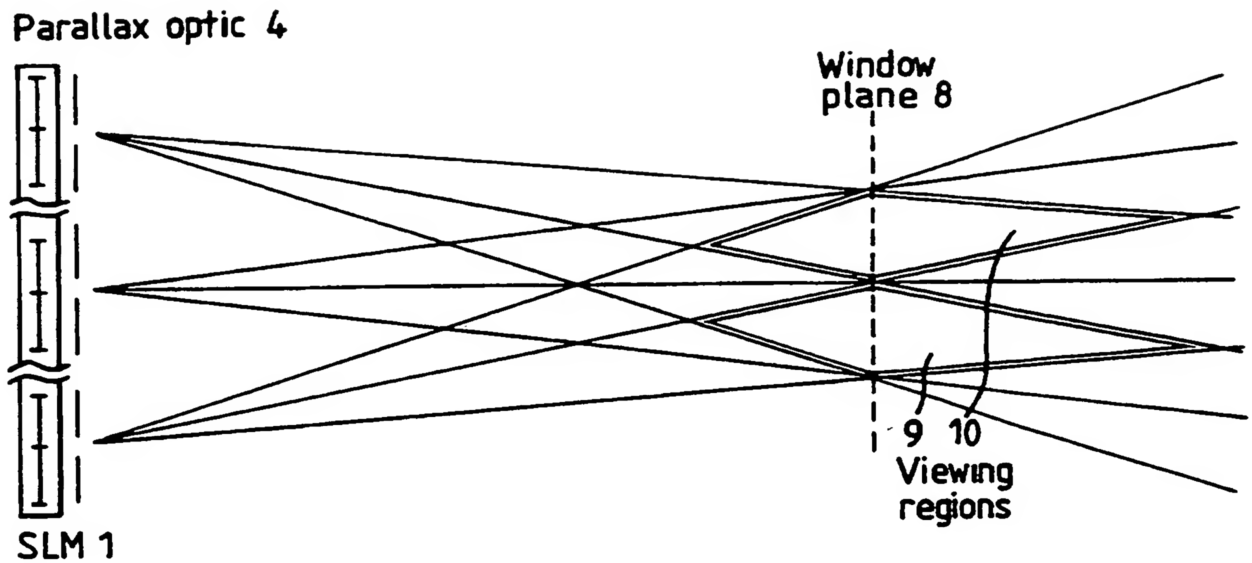
Gaps between pixels 6
SLM columns of pixels 5
Parallax barrier 4
Spit 7
3
Backlight
Column 3
Column 2
Column 1
To Window 1
To Window 2
To Window 3
Glass substrates 2
SLM 1

FIG.1

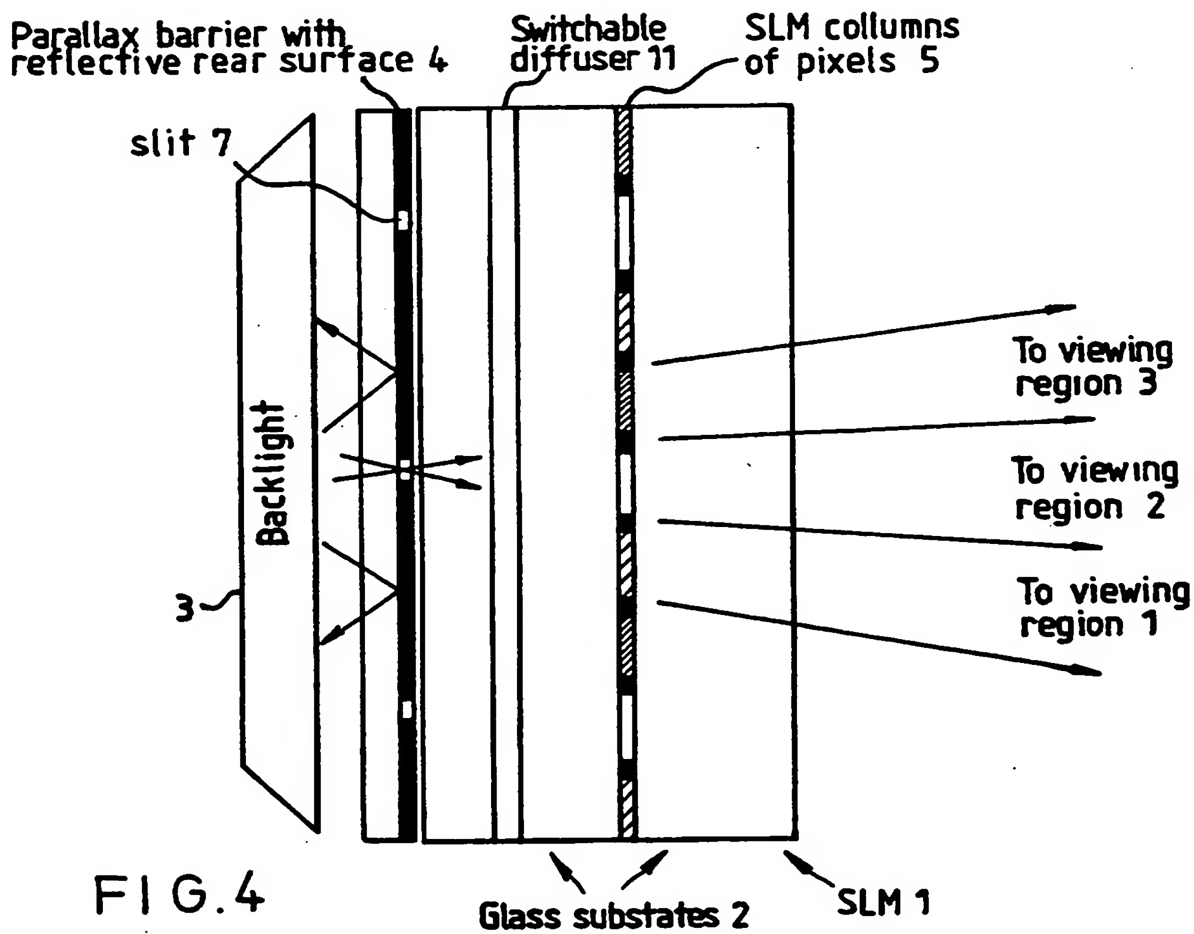


Parallax optic 4
Image 1
Image 2
Image 1
Image 2
Image 1
Image 2
SLM 1

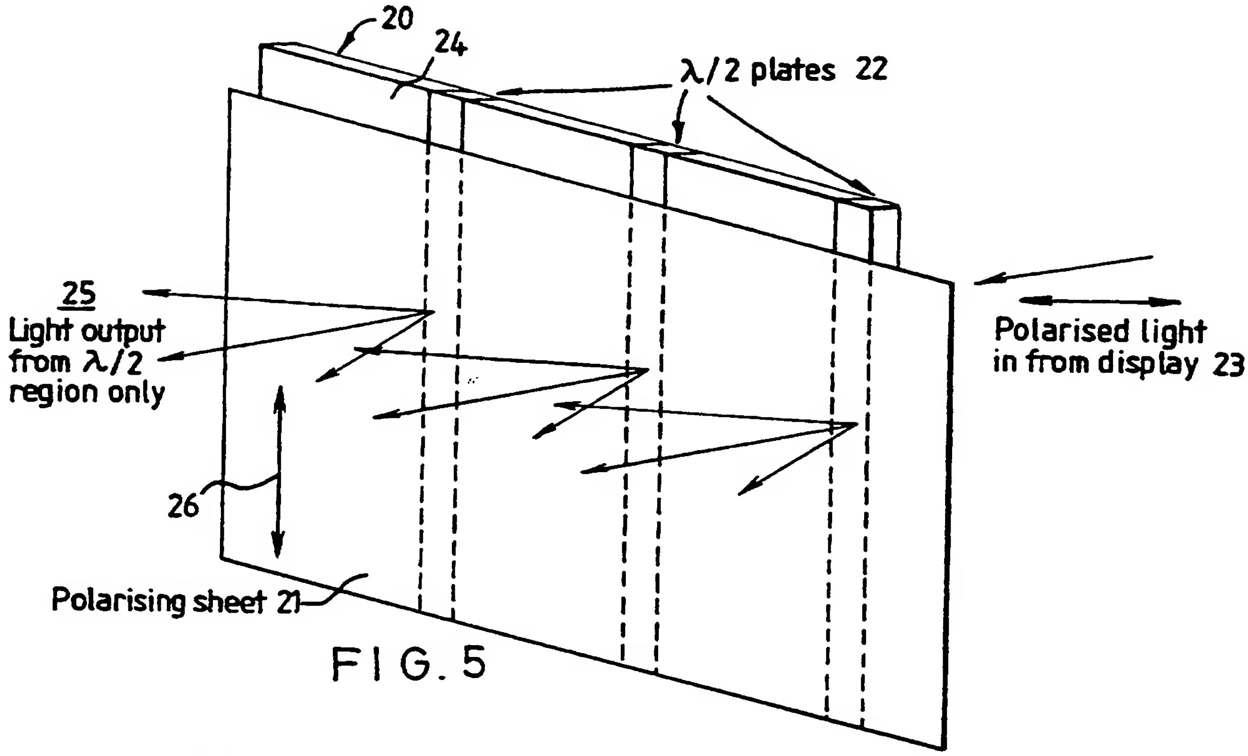
FIG.2


Parallax optic 4
Window plane 8
9
10
Viewing regions
SLM 1

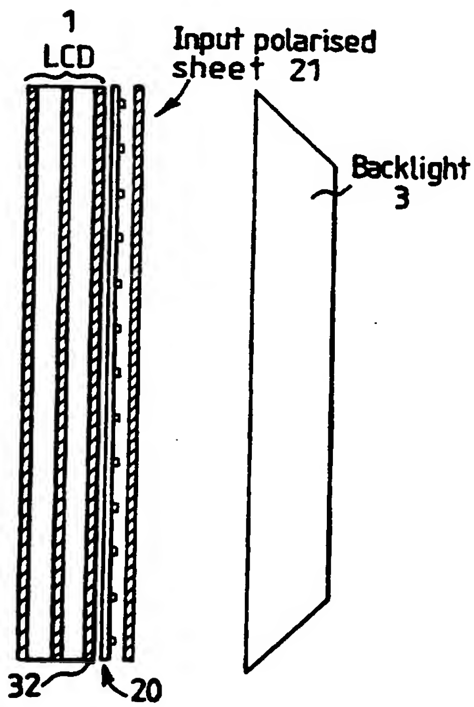
F I G.3


Parallax barrier with reflective rear surface 4
Switchable diffuser 11
SLM collumns of pixels 5
slit 7
Backlight
3
To viewing region 3
To viewing region 2
To viewing region 1
Glass substates 2
SLM 1

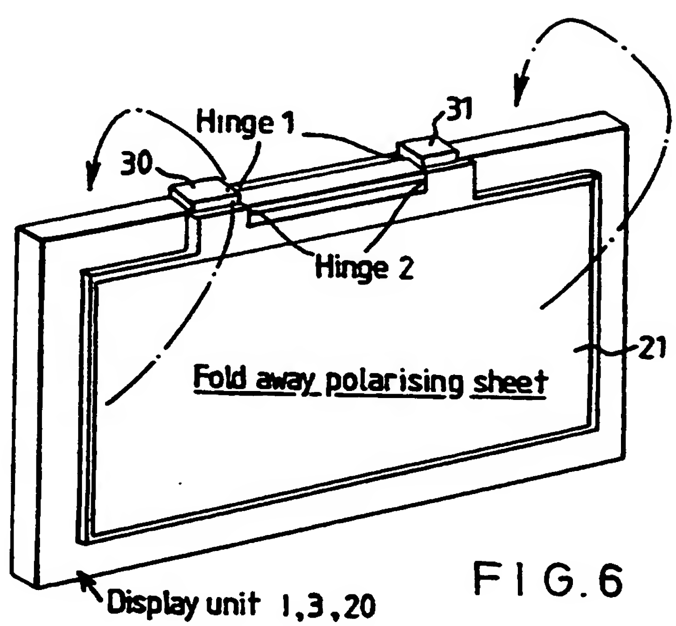
F I G.4



F I G. 5



F I G. 7



F I G. 6

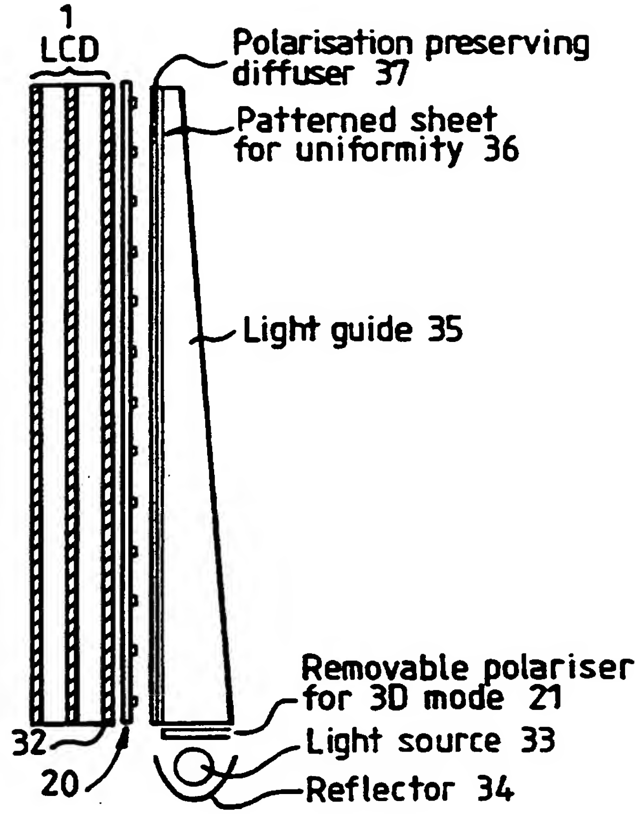

1
LCD
Polarisation preserving diffuser 37
Patterned sheet for uniformity 36
Light guide 35
Removable polariser for 3D mode 21
Light source 33
Reflector 34
32
20

FIG.8

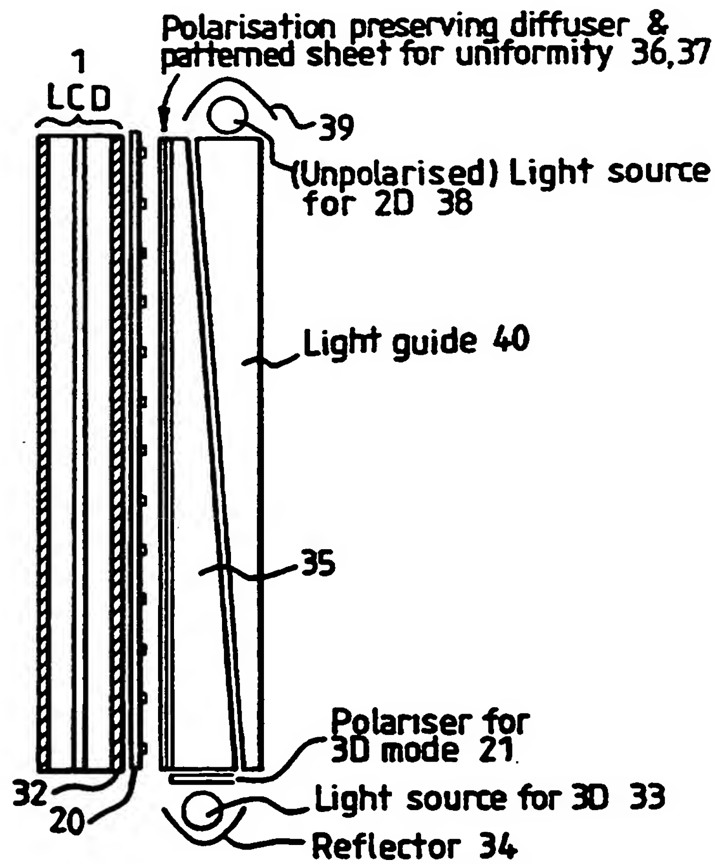

Polarisation preserving diffuser & patterned sheet for uniformity 36,37
1
LCD
39
(Unpolarised) Light source for 2D 38
Light guide 40
35
Polariser for 3D mode 21
Light source for 3D 33
Reflector 34
32
20

FIG.9

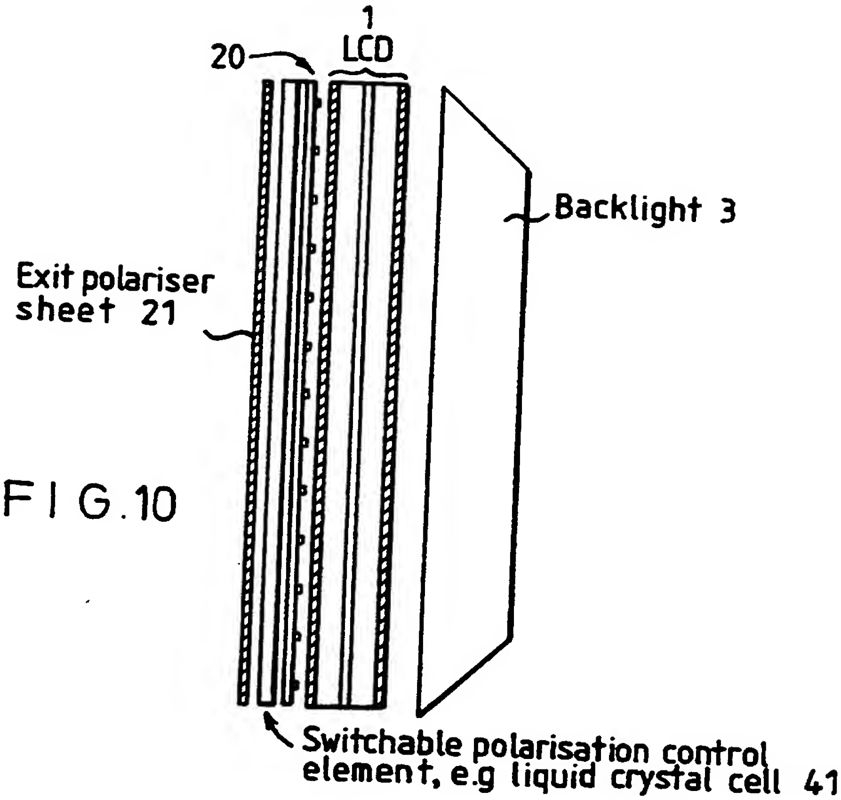

20
1
LCD
Backlight 3
Exit polariser sheet 21
Switchable polarisation control element, e.g liquid crystal cell 41

FIG.10

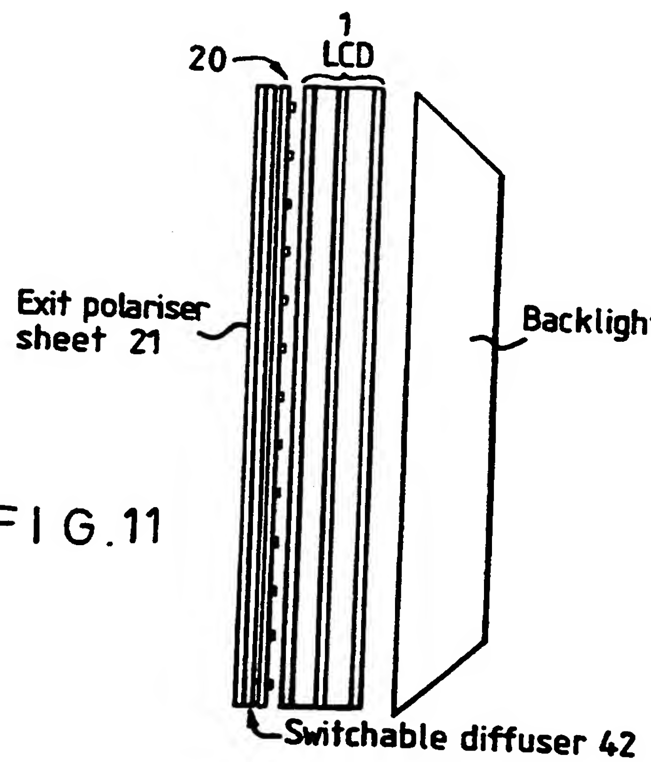
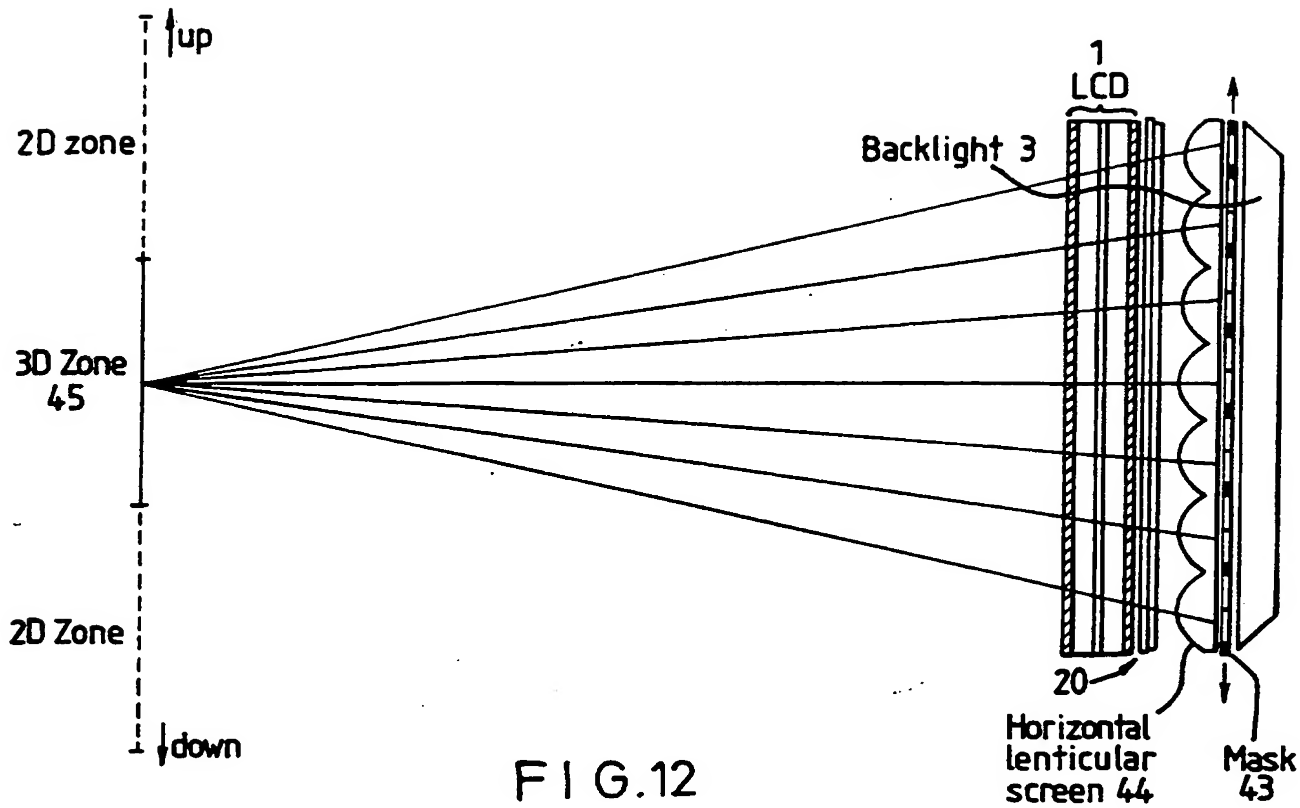
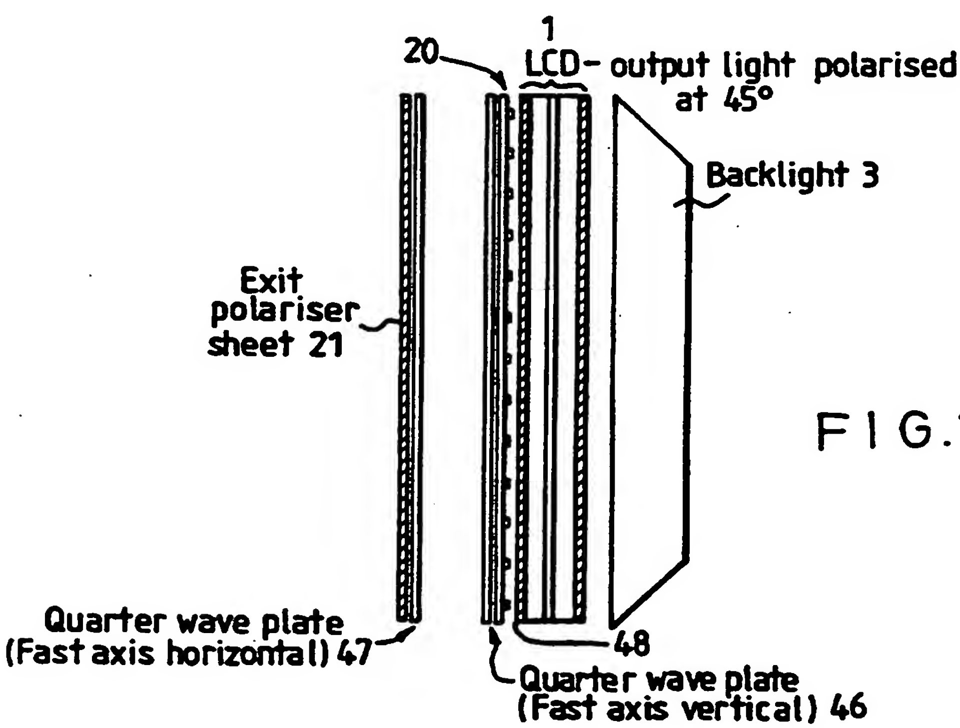

20
1
LCD
Exit polariser sheet 21
Backlight 3
Switchable diffuser 42

FIG.11


up
2D zone
3D Zone
45
2D Zone
down
1
LCD
Backlight 3
20
Horizontal
lenticular
screen 44
Mask
43

F I G.12


20
1
LCD- output light polarised
at 45°
Backlight 3
Exit
polariser
sheet 21
Quarter wave plate
(Fast axis horizontal) 47
48
Quarter wave plate
(Fast axis vertical) 46

F I G.15

FIG.13

Half wave retarder between polarisers

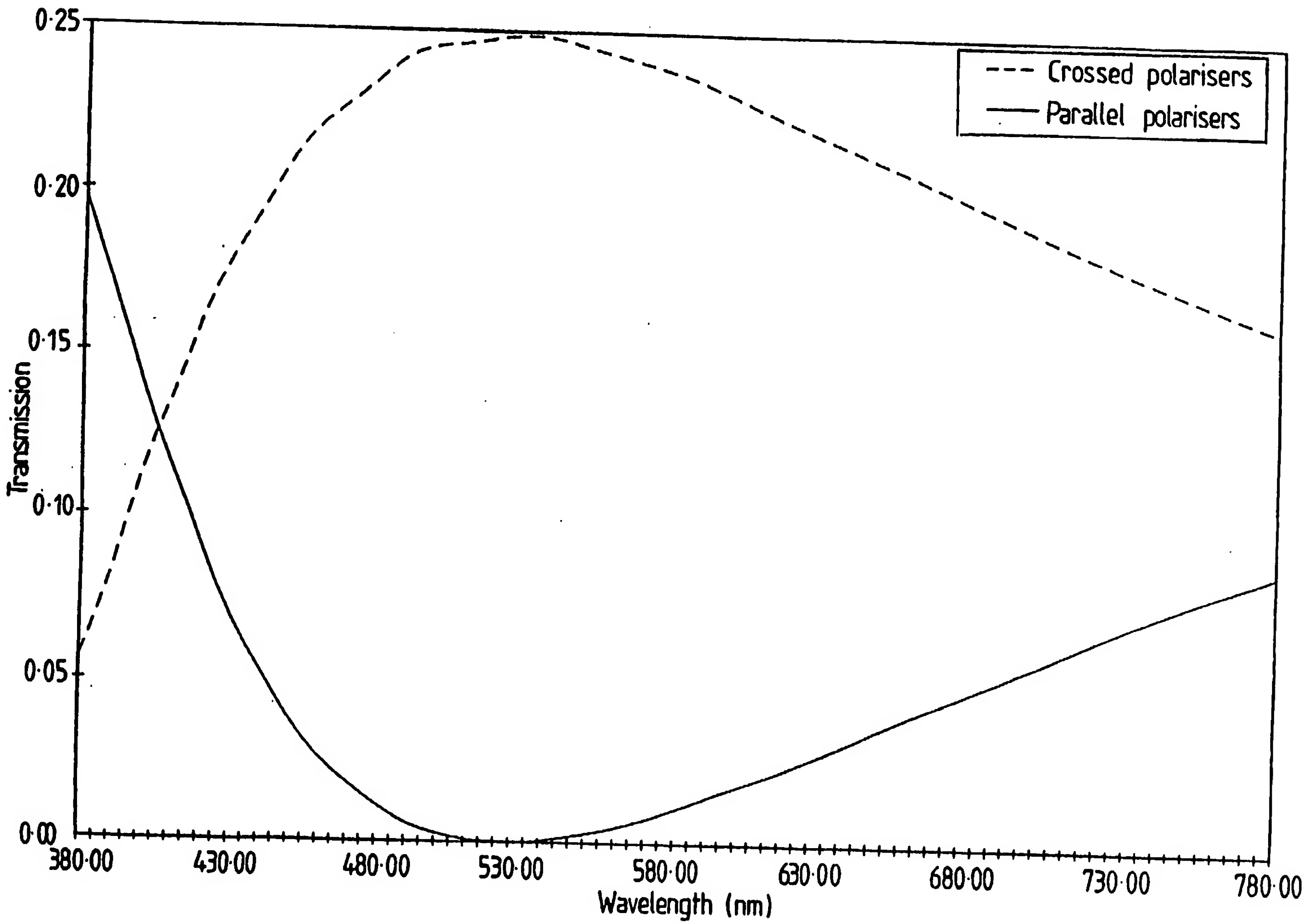
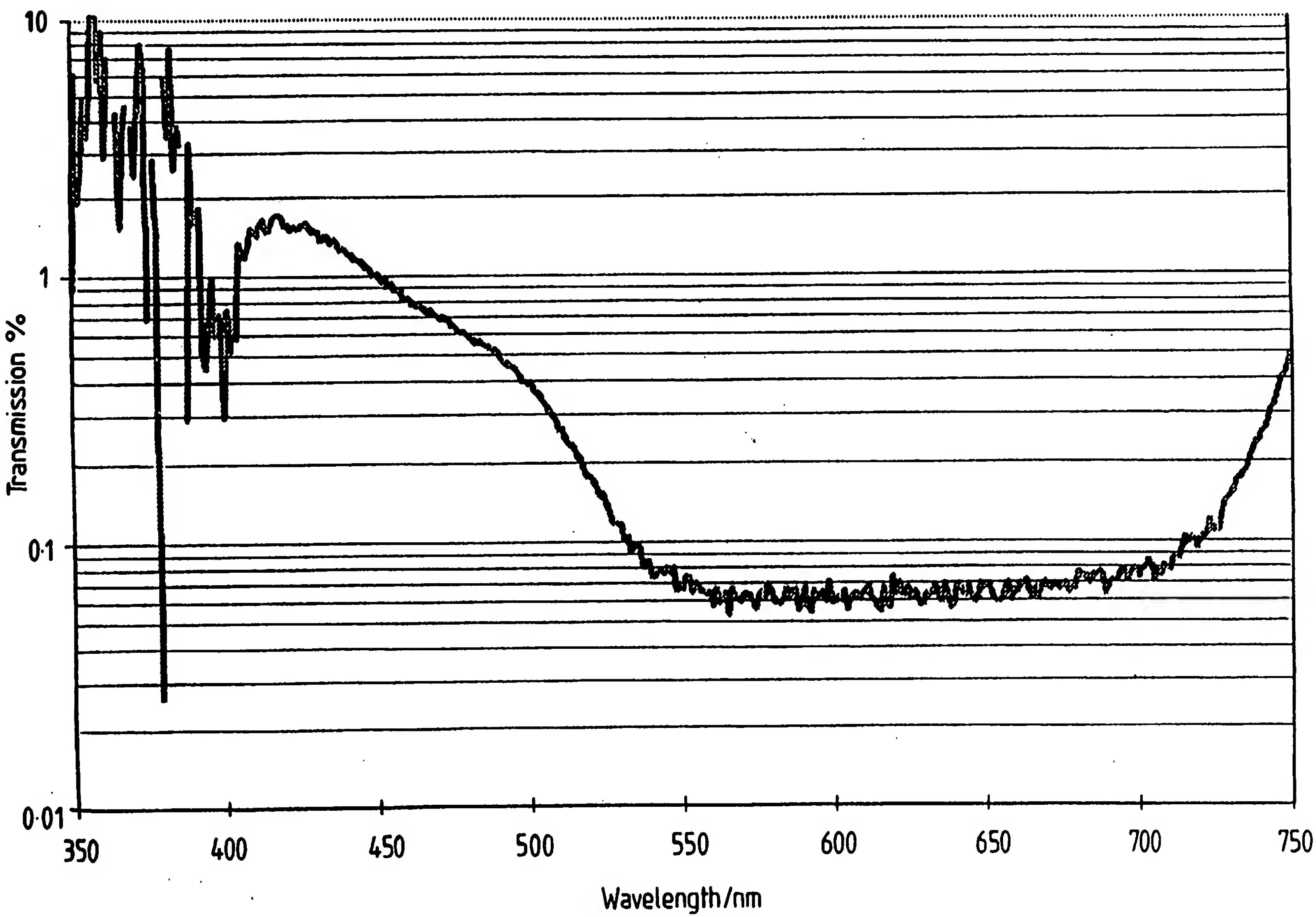
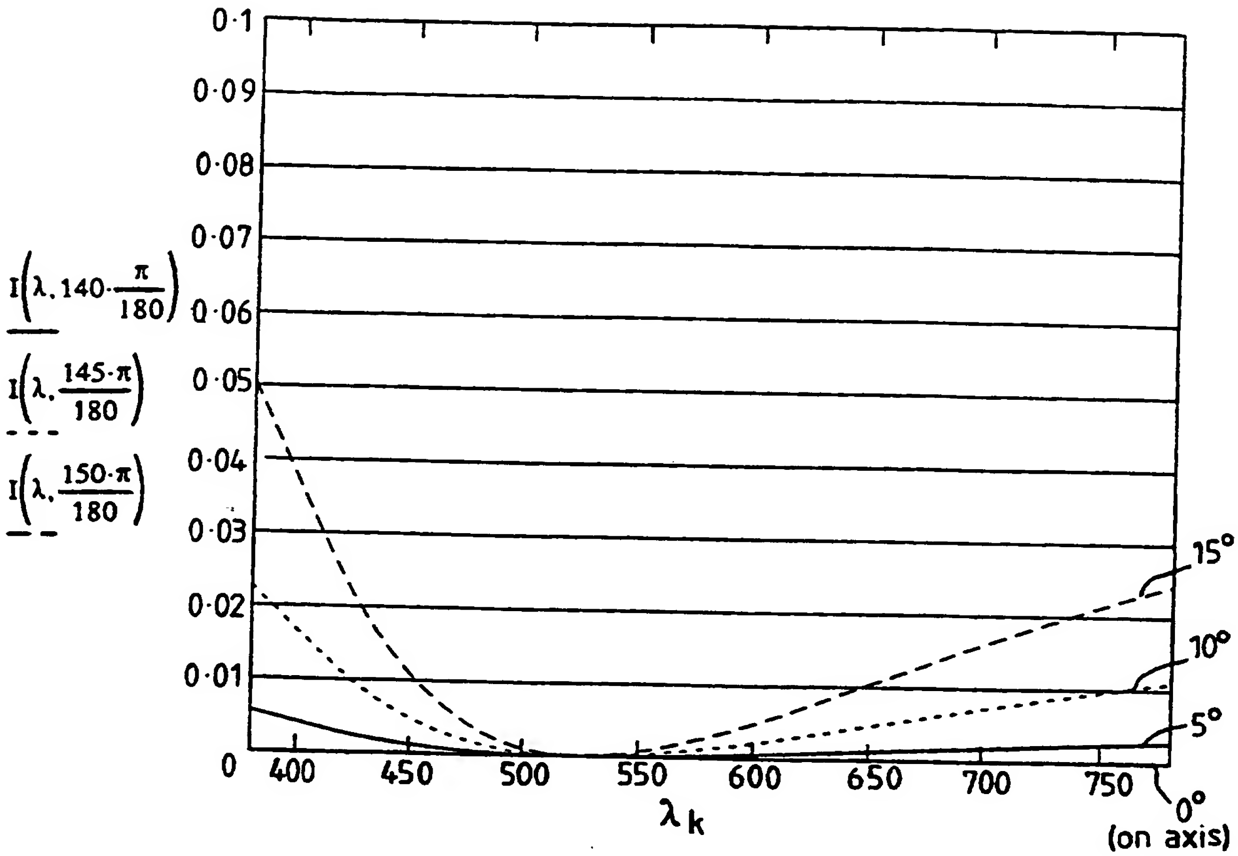


FIG.14


10
1
0·1
0·01
Transmission %
350
400
450
500
550
600
650
700
750
Wavelength/nm



0·1
0·09
0·08
0·07
0·06
0·05
0·04
0·03
0·02
0·01
0
$I\left(\lambda, 140\cdot\frac{\pi}{180}\right)$
$I\left(\lambda, \frac{145\cdot\pi}{180}\right)$
$I\left(\lambda, \frac{150\cdot\pi}{180}\right)$
400
450
500
550
600
650
700
750
λ_k
15°
10°
5°
0°
(on axis)

F I G. 16

2317295

PARALLAX BARRIER AND DISPLAY.

The present invention relates to a parallax barrier and to a display. Such displays may be used as switchable two dimensional (2D)/three dimensional (3D) displays and may be used in games apparatuses, computer monitors, lap top displays, work stations and professional imaging, for instance for medical, design or architectural use.

In normal vision, the two human eyes perceive views of the world from two different perspectives due to their spatial separation within the head. These two perspectives are then used by the brain to assess the distance to various objections in a scene. In order to provide a display which effectively displays a 3D image, it is necessary to recreate this situation and supply a so-called "stereoscopic pair" of images, one to each eye of an observer.

Most 3D displays may be classified into two types depending on the technique used to supply the different views to the eyes. Stereoscopic displays typically display both of the images over a wide viewing area. However, each of the views is encoded, for instance by colour, polarisation state or time of display, so that a filter system of glasses worn by the observer attempts to separate the views to let each eye see only the view that is intended for it.

Autostereoscopic displays require no viewing aids to be worn by the observer. Instead, the two views are only visible from defined regions of space. In a region of space in which an image is visible across the

whole of the display active area is termed a "viewing region". If the observer is situated such that one eye is in one viewing region and the other eye is in the other viewing region, then a correct set of views is seen and a 3D image is perceived.

For autostereoscopic displays of the "flat panel" type, the viewing regions are formed by a combination of the picture element (pixel) structure of the display and an optical element, generically termed a parallax optic. An example of such an optic is a parallax barrier. This element is a screen with vertical transmissive slits separated by opaque regions. A display of this type is illustrated in Figure 1 of the accompanying drawings. A spatial light modulator (SLM)1 of the liquid crystal type comprises glass substrates 2 between which are disposed a liquid crystal layer together with associated electrodes and alignment layers. A backlight 3 illuminates the SLM 1 from behind and a parallax barrier 4 is disposed on the front surface of the SLM 1.

The SLM 1 comprises a 2D array of pixel apertures with the pixels arranged as columns as shown at 5 separated by gaps 6. The parallax barrier 4 has vertically extending slits 7 with a horizontal pitch close to an integer multiple of the horizontal pitch of the pixel columns 5 so that groups of columns of pixels are associated with each slit. As illustrated in Figure 1, three pixel columns labelled columns 1, 2 and 3 are associated with each slit 7 of the parallax barrier 4.

The function of the parallax optic such as the parallax barrier 4 is to restrict the light transmitted through the pixels to certain output angles. This restriction defines the angle of view of each of the pixel columns behind the associated slit. The angular range of view of each pixel is

determined by the pixel width and the separation between planes containing the pixels and the parallax optic. As shown in Figure 1, the three columns 5 associated with each slit 7 are visible in respective viewing windows.

Figure 2 of the accompanying drawings illustrates the angular zones of light created from an SLM 1 and a parallax barrier 4 where the parallax barrier slits have a horizontal pitch equal to an exact integer multiple of the pixel column pitch. In this case, the angular zones coming from different locations across the display surface intermix and a pure zone of view for image 1 or image 2 does not exist. Thus, each eye of an observer will not see a single image across the whole of the display but instead will see slices of different images at different regions on the display surface. In order to overcome this problem, the pitch of the parallax optic is reduced slightly so that the angular zones converge at a predetermined plane, generally known as the "window plane", in front of the display. This change in the parallax optic pitch is termed "viewpoint correction" and is illustrated in Figure 3 of the accompanying drawings. The window plane is shown at 8 and the resulting substantially kite shaped viewing regions are shown at 9 and 10. Provided the left and right eyes of the observer remain in the viewing regions 9 and 10, respectively, each eye will see the single image intended for it across the whole of the display so that the observer will perceive the 3D effect.

The window plane 8 defines the optimum viewing distance of the display. An observer whose eyes are located in this plane receives the best performance of the display. As the eyes move laterally in this plane, the image on the display remains until the eyes reach the edge of the viewing regions 9 and 10, whereupon the whole display swiftly changes

to the next image as one eye moves into the adjacent viewing region. The line of the window plane within each viewing region is generally termed a "viewing window". Figure 4 of the accompanying drawings illustrates an autostereoscopic display which differs from that shown in Figure 1 in that the parallax barrier 4 is disposed on the rear surface of the SLM 1. This arrangement has the advantage that the barrier 4 is disposed behind the SLM 1 away from possible damage. Also, the light efficiency of the display may be improved by making the opaque parts of the rear surface of the parallax barrier 4 reflective so as to recycle light which is not incident on the slits 7.

A switchable diffuser 11 is shown between the parallax barrier 4 and the SLM 1. Such a diffuser may comprise a polymer-dispersed liquid crystal which is switchable between a low scattering or substantially clear state and a highly scattering state. In the low scattering state, the display operates as described hereinbefore as an autostereoscopic 3D display. When the diffuser is switched to the highly scattering state, light rays are deflected on passing through the diffuser and form an even or "Lambertian" distribution which "washes out" the effect of the parallax barrier 4 and so destroys the creation of viewing regions. In this mode, the display therefore acts as a conventional 2D display with the full spatial resolution of the SLM 1 being available for displaying 2D images.

In the displays described hereinbefore, the basic principle is that a subset of the total number of pixels of the SLM 1 is visible to each eye at any one time. Thus, each of the views represented in the viewing regions uses a fraction of the total resolution of the SLM 1. In a typical two view spatially multiplexed autostereoscopic display, each eye perceives an image of only half the total resolution. For a three view system, the

resolution in each eye is only one third. The representation of complex small characters, such as text and details within images, may therefore be adversely affected. It is desirable to include in the display some means for disabling or overcoming the parallax imaging system so that the full resolution of the SLM 1 is visible to each eye for the display of detailed 2D information. Although the switchable diffuser 11 shown in Figure 4 provides such switching, this adds to the cost and complexity of the display.

US 2 631 496 discloses an autostereoscopic display based on a single picture in which a parallax element is provided by a polariser element having alternate stripes of orthogonally oriented polariser. The polariser element cooperates with an image in which the left and right views are encoded with orthogonal polarisation in vertical columns. The encoding swaps for every image strip column. The polariser element thus acts in a similar manner to a parallax barrier but is such that the mark/space ratio i.e. the ratio of the width of each effective slit to each effective opaque region, is substantially equal to 1. This results in relatively high cross talk and poor viewing freedom for the observer. Such an arrangement does not permit a full resolution 2D viewing mode to be achieved without image artefacts.

Proc. SPIE vol. 2177, pp 181 "Novel 3D Stereoscopic Imaging Technology", S.M. Faris, 1994 discloses a display which may operated stereoscopically or autostereoscopically using external micropolarisers. In particular, two micropolariser sheets are disposed above the spatially multiplexed image and are movable to switch between autostereoscopic and stereoscopic viewing. Such an arrangement cannot be operated to provide a high resolution 2D viewing mode.

E. Nakayama et al, "2D/3D Compatible LC Display without Special Glasses", Proc. third Internal Display Workshops vol. 2, pp 453-456, 1996 discloses a 3D display of the rear parallax barrier type similar to that shown in Figure 4 of the accompanying drawings. A switchable diffuser is disposed between the parallax barrier and the SLM in the same way as illustrated in Figure 4 to allow the display to be operated in a full resolution 2D mode.

In order to destroy the formation of viewing windows for the 2D mode, scattering by the diffuser must completely remove the visibility of the parallax barrier to the observer. However, in order for the autostereoscopic 3D mode to be effective, the gaps between the slits of the parallax barrier must provide strong extinction of light. These requirements are mutually incompatible and can be overcome only by very strong back-scattering in the switchable diffuser, which reduces the display transmission substantially, or by making the parallax barrier reflective on the observer side, thus damaging the 3D image. Further, although a rear reflective layer may be applied to the parallax barrier so as to recycle light and improve brightness, all of the light received by the observer has to pass through the slits of the parallax barrier so that display brightness is degraded in the 2D mode. Typically, the mark space ratio of the parallax barrier would be 2:1 so that only one third of the light from the backlight is transmitted through the display. The reflective layer may improve this but would not restore the display to full brightness. Further, back scatter in the switchable diffuser reduced the display brightness in the 2D mode. If the switchable diffuser is designed for strong backscatter in the high diffusion mode of operation, it is difficult to achieve the very low levels of diffusion necessary in the low

diffusion mode to ensure that the 3D display device does not suffer from increased cross talk.

J.B. Eichenlaub, Proc. SPIE 2177, pp 4-15, "An Autostereoscopic Display with High Brightness and Power Efficiency", 1994 discloses a 3D display of the rear parallax barrier type which could be switched to a full resolution 2D mode using a switchable diffuser or an array of lamps. However, such an arrangement has the disadvantages described hereinbefore. Furthermore, the optical system of such a display is not compatible with the slim design of current flat-panel display systems wherein the backlight structure is less than 2 cm. thick.

According to a first aspect of the invention, there is provided a parallax barrier comprising: a polarisation modifying layer having aperture regions, for supplying light of a second polarisation when receiving light of a first polarisation, separated by barrier regions, for supplying light of a third polarisation different from the second polarisation when receiving light of the first polarisation; and a polariser selectively operable in a first mode to pass light of the second polarisation and to block light of the third polarisation and in a second mode to pass light of the second and third polarisations.

Such a parallax barrier can therefore be operated in a parallax barrier mode or in a non-barrier mode. When illuminated by light of the first polarisation, the non-barrier mode permits substantially all of the light to be transmitted so that, when used in a 3D autostereoscopic display, a full resolution 2D mode of high brightness can be provided.

The aperture regions may comprise parallel elongate slit regions.

The polariser may be a uniform polariser.

The third polarisation may be orthogonal to the second polarisation.

The first, second and third polarisations may be linear polarisations. The aperture regions may be arranged to rotate the polarisation of light and the barrier regions may be arranged not to rotate the polarisation of light so that the third polarisation is the same as the first polarisation. Such an arrangement allows the barrier regions to have maximum achromatic extinction of light when the barrier is used in barrier mode.

The aperture regions may comprise retarders. The aperture regions may comprise half waveplates. As an alternative, the aperture regions may comprise polarisation rotation guides.

The polariser may be removable from a light path through the polarisation modifying layer in the second mode. The polariser does not have to be aligned with great accuracy in order for the barrier mode to be effective. In particular, it is merely necessary for the polariser to cover the polarisation modifying layer and to be reasonably accurately aligned about an axis substantially normal to the layer. Thus, removal of the polariser permits the non-barrier mode of operation and relatively simple and inexpensive alignment means may be provided for aligning the polariser in the barrier mode.

The polariser may comprise glasses to be worn by an observer in the first mode.

The polariser may comprise a polarising layer and a retarder layer which is switchable between a non-retarding mode and a retarding mode providing a quarter wave of retardation.

The polariser may comprise a polarising layer and a switchable diffuser having a diffusing polarising mode and a non-diffusing non-polarising mode. The diffuser may be disposed between the polarising layer and the polarisation modifying layer. As an alternative, the polarisation modifying layer may be disposed between the polarising layer and the diffuser.

The barrier may comprise: a first quarter waveplate disposed between the polarisation modifying layer and the polariser and attached to the polarisation modifying layer; and a second quarter waveplate disposed between the first quarter waveplate and the polariser and attached to the polariser, the first and second quarter waveplates having substantially orthogonal optic axis. The quarter waveplates between the polarisation modifying layer and the polariser convert light to and from circular polarisation so that alignment of the polariser relative to the polarisation modifying layer may be further relaxed.

According to a second aspect of the invention, there is provided a display comprising a barrier according to the first aspect of the invention and a spatial light modulator for supplying light of the first polarisation to the polarisation modifying layer.

The spatial light modulator may be a light emissive device, such as an electroilluminescent display. As an alternative, the spatial light modulator may provide selective attenuation of light and may be

associated with a light source. The spatial light modulator may comprise a liquid crystal device.

According to a third aspect of the invention, there is provided a display comprising a barrier according to the first aspect of the invention, a light source for supplying light to the polariser, and a spatial light modulator having an input polariser for passing light from the aperture regions.

The spatial light modulator may comprise a liquid crystal device.

According to a fourth aspect of the invention, there is provided a display comprising: a light source selectively operable in a first mode for supplying light of a first polarisation and a second mode for supplying unpolarised light; a polarisation modifying layer having aperture regions, for supplying light of a second polarisation when receiving light of the first polarisation, separated by barrier regions, for supplying light of a third polarisation different from the second polarisation when receiving light of the first polarisation; and a spatial light modulator having an input polariser for passing light of the second polarisation and for blocking light of the third polarisation.

The aperture regions may comprise parallel elongate slit regions.

The light source may comprise a polarised light source operable in the first mode and an unpolarised light source operable in the second mode. The polarised light source may comprise at least one first light emitting device arranged to supply light through a polariser to a first light guide. The unpolarised light source may comprise at least one second light emitting device arranged to supply light to a second light guide and one

of the first and second light guides may be arranged to supply light through the other of the first and second light guides.

The light source may comprise at least one light emitting device, a light guide, and a polariser disposed in an optical path between the or each light emitting device and the light guide in the first mode and outside the optical path in the second mode.

According to a fifth aspect of the invention, there is provided a display comprising: a polarisation modifying layer having aperture regions, for supplying light of a second polarisation when receiving light of a first polarisation, separated by barrier regions, for supplying light of a third polarisation different from the second polarisation when receiving light of the first polarisation; a spatial light modulator having an input polariser for passing light of the second polarisation and for blocking light of the third polarisation; a light source; a mask having polarising regions, for supplying light of the first polarisation from the light source, and non-polarising regions, for transmitting light from the light source; and a parallax optic cooperating with the mask to direct light from the polarising regions through the spatial light modulator to a first viewing region and to direct light from the non-polarising regions through the spatial light modulator to a second viewing region.

The mask may be movable relative to the parallax optic for moving the first and second viewing regions.

The parallax optic may comprise an array of parallax generating elements.

The aperture regions may comprise parallel elongate slit regions.

Each of the parallax generating elements may be optically cylindrical with an axis substantially orthogonal to the slit regions.

The array may comprise a lenticular screen. As an alternative, the array may comprise a parallax barrier.

The polarising and non-polarising regions may comprise laterally extending strips.

The mask may further comprise opaque regions at least partially separating the polarising regions from the non-polarising regions.

The third polarisation may be orthogonal to the second polarisation.

The first, second and third polarisations may be linear polarisations. The aperture regions may be arranged to rotate the polarisation of light and the barrier regions may be arranged not to rotate the polarisation of light so that the third polarisation is the same as the first polarisation.

The aperture regions may comprise half waveplates.

The aperture regions may comprise polarisation rotation guides. It is thus possible to provide a display, for instance of the flat panel type which is operable in a wide view full resolution 2D mode and in a directional 3D autostereoscopic mode. When embodied as a liquid crystal device whose pixel apertures are at least partially defined by a

black mask, there are no undesirable visual artefacts associated with the black mask in the 2D mode.

The pitch alignment of the polarisation modifying layer determined the parallax barrier pitch, which typically has to be set to within 0.1 micrometres. The barrier may be made of a glass substrate with similar thermal expansivity to the spatial light modulator so as to minimise misalignments during heating of the system between switch on and operating temperatures. The high tolerance alignment can be fixed during manufacture and is unaffected by switching between 2D and 3D modes. There are six critical degrees of freedom alignment tolerances in such displays with respect to the positioning of the apertures of the barrier relative to the spatial light modulator and these do not have to be set in the field. Because the removable or switchable element can be a uniform polarisation element, accurate alignment is only necessary in one degree of freedom i.e. rotation about an axis normal to the display surface. Rotation about the other two axes and spatial positioning may all be set with low and easy to satisfy tolerance requirements. Thus mechanical assembly is substantially simplified and cost, size and weight can be reduced.

It is possible to switch different regions of the display independently to allow 3D and 2D regions to be mixed simultaneously on the display surface.

A colour 3D display can be provided with low cross talk using relatively simple and inexpensive birefringent elements. The 2D mode may be substantially as bright as a conventional display with the same angle of view.

When applied to an observer tracking display, the tracking may be performed by relative movement between the spatial light modulator and the polarisation modifying layer. Thus, the polarisation modifying layer may remain attached to the mechanical system at all times. The polariser does not need to be attached to the mechanical system at all so that mounting is simplified. In fact, the polariser does not need to be mounted in physical proximity to the polarisation modifying layer and may indeed be provided in the form of glasses to be worn by an observer.

The invention will be further described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic horizontal sectional view of a known type of autostereoscopic 3D display;

Figure 2 is a plan view illustrating light cones produced by a non-view point corrected display;

Figure 3 is a view similar to Figure 2 illustrating the creation of viewing regions in a view point corrected display;

Figure 4 is a diagrammatic horizontal sectional view of another known type of autostereoscopic 3D display;

Figure 5 is a diagrammatic view of a parallax barrier constituting an embodiment of the invention;

Figure 6 is a diagrammatic view illustrating an arrangement for switching between modes of the barrier of Figure 5;

Figure 7 is a diagrammatic plan view of an autostereoscopic 3D display constituting an embodiment of the invention;

Figure 8 is a diagrammatic plan view of an autostereoscopic 3D display constituting another embodiment of the invention;

Figure 9 is a diagrammatic plan view of an autostereoscopic 3D display constituting another embodiment of the invention;

Figure 10 is a diagrammatic plan view of an autostereoscopic 3D display constituting another embodiment of the invention;

Figure 11 is a diagrammatic plan view of an autostereoscopic 3D display constituting another embodiment of the invention;

Figure 12 is a diagrammatic side view of an autostereoscopic display constituting another embodiment of the invention;

Figure 13 is a graph of fractional transmission against wavelength in nanometres illustrating transmission of unpolarised light through two polarisers with a half waveplate disposed therebetween;

Figure 14 is a graph of transmission of light in percent against wavelength in nanometres illustrating transmission of light through crossed polarisers;

Figure 15 is a diagrammatic plan view of an autostereoscopic 3D display constituting another embodiment of the invention; and

Figure 16 is a graph of fractional light transmission against wavelength in nanometres illustrating extinction of light through a system comprising crossed polarisers with two quarter waveplates disposed therebetween.

Like reference numerals refer to like parts throughout the drawings.

The parallax barrier shown in Figure 5 comprises a polarisation modifying layer 20 and a polariser in the form of a polarising sheet 21. The polarisation modifying layer 20 comprises aperture regions 22 in the form of parallel elongate slit regions arranged to rotate linear polarisation 23 of incoming light through 90 degrees. The aperture regions 22 are separated by barrier regions such as 24 which are arranged not to affect the polarisation of the incoming light. The regions 22 may for instance comprise half waveplate polarisation retarders or 90 degree polarisation rotators. The aperture regions 22 are disposed at the desired pitch of the parallax barrier, incorporating any viewpoint correction as described hereinbefore, and are of the width required for the parallax barrier slits. Typical values for the pitch and width of such slits are 200 micrometres and 50 micrometres, respectively. The aperture regions 22 have an optic axis aligned so as to rotate the input polarisation through 90 degrees. For instance, when the parallax barrier is disposed in front of a liquid crystal display (LCD) of the thin film transistor (TFT) type, light from the LCD is polarised at +45 degrees to a vertical axis of the LCD with which the strip-shaped aperture regions 22 are parallel. The optic axis is therefore arranged so that the polarisation of light 25 output from the slit regions is at -45 degrees with respect to the same vertical axis. The

barrier regions 24 are transparent regions with little or no effect on the transmitted light, which therefore remains polarised at +45 degrees.

The polarising sheet 21 has a polarising direction indicated at 26 which is substantially orthogonal to the polarisation direction 23 of incoming light and hence of light passing through the regions 24. However, the polarisation direction 26 is parallel to the polarisation direction of light passing through the slit regions 22 so that the parallax barrier operates in a barrier mode with incoming light being transmitted through the slit regions 22 and being substantially blocked or extinguished through the parts of the barrier defined by the barrier regions 24.

In order to operate the parallax barrier in a non-barrier mode, the polarising sheet 21 is disabled, for instance by being removed. In this mode, the strip regions 22 are substantially invisible because they are smaller in width than the visual acuity limit for normal viewing distances. By arranging for the regions 22 and 24 to have substantially the same transmissivity, there should be no undesirable visual artefacts, such as Moire beating with the pixel structure of an associated LCD. Although the slit regions 22 still rotate the polarisation direction of the incident light, this is not visible to the human eye when the polarising sheet 21 has been removed. In this mode, the parallax barrier allows the full spatial resolution of the associated LCD to be available for 2D display with very little attenuation of light. The parallax barrier of Figure 5 may be used to replace the front parallax barrier 4 shown in Figure 1 so as to provide an autostereoscopic 3D display constituting an embodiment of the invention.

A convenient way of arranging for the polariser sheet 21 to be removable is illustrated in Figure 6. The polariser sheet 21 is attached to the remainder of the autostereoscopic display by double hinges 30 and 31. This allows the polariser sheet 21 to be swung over the front of the display with the polariser alignment controlled by the base line of the hinges and optionally further constrained by a location datum on the opposite edge of the polariser sheet from the hinges. In the 2D mode, the polariser is folded over the rear of the display unit and stored flush against the rear of the display unit.

If the parallax barrier 4 in the known types of display such as those shown in Figures 1 and 4 were made removable in order to provide a full resolution high brightness 2D mode of operation, it would have to be provided with mounts which defined the location in 5 degrees of freedom, namely two translation axes and three rotation axes, to positional tolerances of the order of 5 micrometres. It is also particularly difficult to maintain parallelism between the parallax barrier 4 and the SLM 1. Any bow in either element would cause deviations in the window generating Moire pattern. This results in reduced viewing freedom and increased levels of cross talk of the display. A removable element would have to compensate for such bows and this is very difficult to achieved in a robust manner with low cost overheads while preserving ease of use and reasonable bulk in the removable element.

The effective plane of the parallax barrier shown in Figure 5 is at the plane of the polarisation modifying layer 20. The alignment of this layer 20 with the associated LCD determined the optical alignment of the autostereoscopic display. For the parallax barrier shown in Figure 5, the layer 20 may be left permanently affixed to the associated LCD and so

can conform to any bows in the LCD, minimising the degradation to window quality. This ensures rigidity and allows for adhesives or other forms of permanent fixative to be employed, for instance during manufacture or as a subsequent fitment using precision alignment tools which are available on LCD production lines. The removable polarising sheet 21 merely needs to be realigned in one rotational axis on replacement in front of the sheet 20. The tolerance on translational position is merely that the whole of the display surface be covered by the polariser sheet 21 and rotations around axes in the plane of the display surface do not affect the polarisation absorbtion axis. Accordingly, the only requirement is for rotational alignment about an axis normal to the display surface to ensure good extinction of light from the barrier regions 24. In order to reduce light leakage from the barrier regions 24 to below 1%, the alignment tolerance is of the order of plus or minus 5 degrees and this is easy to satisfy.

Figure 7 illustrates the use of the parallax barrier of Figure 5 in rear parallax barrier autostereoscopic display. The polarisation modifying layer 20 is disposed adjacent the LCD 1 and the polariser sheet 21 acts as an input polariser and is disposed between the layer 20 and the backlight 3. The LCD 1 has an input polariser 32 whose polarisation direction is aligned so as to pass light from the strip regions 22 and to block light from the barrier regions 24. Thus, the polarisation directions of the input polariser sheet 21 and the LCD polariser 32 are orthogonal. In order to provide a full resolution high brightness 2D mode, the polariser sheet 21 is removed from the light path.

Figure 8 illustrates a rear parallax barrier display in which the removable polariser 21 forms part of the backlight. The backlight comprises a light

source 33 and a reflector 34 which, in the 3D mode, direct light through the polariser sheet 21 into a light guide 35. The light guide 35 has on its output surface a patterned sheet 36 for providing uniformity of illumination of the LCD 1 and a polarisation preserving diffuser 37 to scatter the output light into a wider range of angles.

This arrangement allows the use of a relatively small polariser 21 at the input surface of the light guide 35. The polariser 21 can be moved out of the light path by a relatively short movement in order to achieve the full resolution high brightness 2D mode of operation.

Figure 9 illustrates an autostereoscopic display having a polarised light source of the type illustrated in Figure 8 but in which the polariser 21 is fixed at the input of the light guide 35. The light source 33 is illuminated for 3D operation.

The display comprises a further unpolarised backlight in the form of a light source 38, a reflector 39 and a light guide 40. The light guides 35 and 40 are disposed such that output light from the light guide 40 passes through the light guide 35. In the full resolution high brightness 2D mode, the light source 33 is extinguished and the light source 39 is illuminated so that unpolarised light passes through the light guide 35 and illuminates the LCD 1 through the layer 20.

Figure 10 shows an example of a front parallax barrier autostereoscopic display which is switchable between 3D and 2D modes without requiring any mechanical movement. The polarisation modifying layer 20 is disposed adjacent the output surface of the LCD 1 and the exit polariser sheet 21 is located at the output of the display. A switchable

polarisation control element 41 is disposed between the sheet polariser 21 and the layer 20. The control element 41, which may be embodied as a liquid crystal cell, is switchable between a state in which it does not effect the transmitted polarisation and a state which causes the polarisation states to be equally transmitted through the sheet polariser 21. For instance, the element 41 may be switched to act as a quarter waveplate with the optic axis at 45 degrees to the polarising axis of the sheet polariser 21. In this state, the linear polarisations from the regions 22 and 24 are both converted to circular polarisations of opposite handedness of which 50% is transmitted by the sheet polariser 21. Alternative liquid crystal embodiments of the element 41 exist, such as phase change guest-host devices.

An advantage of this type of arrangement is that the control element 41 may be spatially controlled so that the two modes co-exist in different regions. This allows some parts of the display to operate in the 2D mode and other parts in the 3D mode.

The display shown in Figure 11 differs from that shown in Figure 10 in that the switchable polarisation control element 41 is replaced by a switchable diffuser 42. The diffuser 42 is switchable electronically between depolarising and non-depolarising states. Such a diffuser may be embodied as a polymer dispersed liquid crystal device.

In its low diffusing state, the switchable diffuser 42 has substantially no effect on operation so that the display operates in the autostereoscopic 3D mode. In the more highly diffusing state, the diffuser 42 has two effects. Firstly, the diffuser destroys the polarisation of incident light so that light from the regions 22 and 24 are transmitted substantially equally

through the exist polariser sheet 21. Secondly, the diffuser destroys the directionality of light through the system by scattering the transmitted light into random directions. However, the scattering effect of the diffuser 42 does not need to be strong because the loss of polarisation is sufficient to cause the display to operate in the 2D mode. The diffuser 42 is merely required to provide sufficient scattering for an adequate angle of view of the display. Thus, the diffuser 42 is required to provide less dense scattering of light than for known types of system so that a brighter 2D mode may be achieved.

A switchable diffuser 42 may also be used in rear parallax barrier arrangements. The diffuser 42 may also be controllable so that different regions can be controlled to operate in different modes so as to provide a display in which some regions operate in the 2D mode and others simultaneously operate in the 3D mode.

Figure 12 illustrates a display of the rear parallax barrier type similar to that shown in Figure 7 but in which the polariser sheet 21 is replaced by a mask 43 and a parallax optic 44 which is illustrated as a lenticular screen but which may alternatively comprise a parallax barrier. The mask 43 comprises horizontal strips arranged, for example, as groups of three strips with each group comprising a polarising strip, a clear strip and an opaque strip. Each group of strips is associated with a parallax element, in the form of a lenticule, of the lenticular screen 44.

The mask 43 is vertically movable with respect to the lenticular screen 44. In the position illustrated in Figure 12, the polarising strips are aligned with the lenticules of the screen 44 so as to provide 3D operation with an observer located in a zone indicated at 45. An

observer in the zone 45, which is the normal viewing zone of the display, can thus perceive a 3D image.

When 2D operation is required, the mask 43 is moved relative to the screen 44 so that the clear strips are imaged into the zone 45. This allows the display to operate in the full resolution high brightness 2D mode. Switching between 3D and 2D modes can therefore be achieved by a relatively small movement. The dark or opaque strips are used to avoid leakage of polarised light into the unpolarised viewing region and vice versa.

The mask 43 may be made by any suitable method, such as that disclosed in JP 63-158525A.

Although the optical functions of the regions 22 and 24 of the parallax barrier could be reversed so that the barrier regions 24 rotate the polarisation and the strip regions 22 have substantially no effect on polarisation, the arrangement described hereinbefore with reference to Figure 5 is generally preferred. In particular, the dark level of the opaque regions formed by the barrier regions 24 and the associated regions of the polariser sheet 21 are effectively provided by two crossed polarisers without any intermediate (optically active) element. This provides strong extinction of light over a broad range of wavelengths and so minimises cross talk in the display.

A possible alternative arrangement of the parallax barrier in the displays is for the two polarisers to have parallel polarisation directions, the barrier regions 24 to be optically active in order to provide the polarisation rotation, and the slit regions 22 not to affect polarisation. As

described hereinbefore, in such an arrangement, the critical opaque regions of the barrier rely on the performance of the polarisation rotating material to achieve high extinction and light leakage of less than 1%. A possible means for achieving this makes use of a polymerised layer of twisted nematic liquid crystal having a thickness which satisfies the first minimum criterion as the regions 24. An advantage of such an arrangement is that the slit regions 22 are neutral and therefore have optimum chromatic performance to provide a 3D mode with reduced colour imbalance.

The polarisation rotation performed by the strip regions 22 does not generally work optimally over such a broad range of wavelengths. Thus, some parts of the visible spectrum are transmitted less than others. Figure 13 illustrates the calculated transmission of unpolarised light through an output polariser of the LCD 1, a waveplate made of a uniaxial birefringent material known as RM257 available from Merck (UK), and the polariser sheet 21. When the two polarisers have their polarising axes crossed, transmission is highest by design at the centre of the visible spectrum but declines towards either end of the visible spectrum. If the centre wavelength is correctly chosen, the transmitted light maintains a good white colour balance. It may be necessary to adjust the balance between red, green and blue colour channels of the LCD 1 to ensure correct colour display in the 3D mode. Such colour balance change may, for example, be precalibrated and set in drivers for the 3D image software or in the design of colour filters of the LCD to optimise between 2D and 3D colour spectra.

The curve shown in Figure 13 for parallel polarisers is that which would have applied to the opaque barrier regions if the barrier regions 24 had

rotated that polarisation. The centre wavelength of the system provides good extinction of light. However, towards the edges of the spectrum, the transmission substantially increases. In order to ensure cross talk levels of not more than 1%, the barrier must provide a 100:1 contrast ratio across the visible spectrum. As indicated by Figure 13, this would not be achieved with parallel polarisers and polarisation rotators as the barrier regions 24.

Figure 14 illustrates the transmission performance through two crossed polarisers without any intermediate optical element. The extinction of light is substantially improved and the desired contrast ratio is achieved throughout the whole range of wavelength from 450 to 750 nanometres. This arrangement with, for instance, waveplates creating the slit apertures and crossed polarisers defining the opaque regions of the barrier is therefore the optimum configuration for most applications.

The polarisation modifying layer 20 may be made, for example, by the deposition of a layer of reactive mesogen, such as RM257, which is patterned by standard photolithographic techniques into the slit structure. A convenient mask for etching is an existing parallax barrier.

The polarisation rotation may be achieved by means of at least two physical effects. According to the first, polarisation rotation is provided by an optical retarder which employs a birefringent material. Such a material is characterised in that the refractive index for light propagating in the material depends on the orientation of the polarisation with respect to the optic axis of the material. The optic axis is set by molecular or crystalline structure of the material. In the case of a uniaxial birefringent material, there is one refractive index for light

propagating with a plane of polarisation parallel to the optic axis and another refractive index for light propagating with a plane of polarisation perpendicular to the optic axis. Light with a plane of polarisation between these may be considered as a sum of these polarisations without loss in generality. If the material is given a thickness t such that light of wavelength λ suffers a phase delay of π between the fast and slow polarisations, then the element is termed a "half waveplate" or "$\lambda/2$ plate". The thickness is then given by:

$$t = m\lambda/2\Delta n$$

where Δn is the difference between the two refractive indices and m is an integer.

Plane polarised light forming on such an optical element undergoes a rotation in the plane of polarisation of twice the angle between the incident plane of polarisation and the optic axis of the material. Thus, if a half waveplate is oriented at 45 degrees to the incident plane of polarisation, the light exits the element with a 90 degree change in the plane of polarisation.

A second physical effect is that produced by a polarisation rotator. Such an element, which may be embodied by a reactive mesogen with a chiral dopant, comprises a material which is birefringent in any one thin slice but in which the angle of the optic axis rotates in a defined manner between slices to describe a spiral. Such an optical element causes polarisation rotation by guiding and can be made to rotate an incident plane of polarisation through 90 degrees for a broad range of wavelengths.

The rotation of the polarisation may further be provided by a combination of these two effects, for instance in order to optimise device performance.

The tolerance of the angular alignment of the polariser sheet 21 with respect to the LCD 1 is determined by the level of light leakage which may be tolerated through the opaque regions of the parallax barrier. Such leakage must be very low and preferably less than 1%. The extinction of light from two perfect crossed polarisers with an angle θ between their axes is given by:

$$I(\theta) = I(0)\cos^2(\theta)$$

the rotational angles for 1% of light leakage are given by the solutions to the equation $I(\theta)/I(0) = 0.01$ and the angles are $\theta = 84.3°$, $95.7°$. Thus, there is a tolerance of approximately plus and minus 5 degrees about the ideal value of 90 degrees. Such an angular tolerance can easily be achieved by simple mechanics or alignment by eye against a reference mark.

Figure 15 illustrates a front parallax barrier type of display in which the parallax barrier is modified by the provision of a quarter waveplate 46 fixed to the layer 20 with its fast axis vertical and a quarter waveplate 47 fixed to the polariser sheet 21 with its fast axis horizontal. The polarising directions of the polariser sheet 21 and an output polariser 48 of the LCD 1 are at minus and plus 45 degrees, respectively.

The quarter waveplate 46 converts the linearly polarised light from the layer 20 to circularly polarised light. Similarly, the quarter waveplate 47 converts the circularly polarised light back to linearly polarised light. With such an arrangement, the angular alignment tolerance can in theory

be completely removed but can, in practice, be substantially relaxed. In practice, quarter waveplates are only "perfect" at their design wavelength. At other wavelengths, the retardance within the plate is not correct to generate perfect circular polarisation and an elliptical state results. However, if the two quarter waveplates 46 and 47 are arranged such that their optical axes are mutually orthogonal, then the inaccuracy in retardance of one plate is substantially cancelled by the inaccuracy in the other plate.

As the polariser sheet 21 and the quarter waveplate 47 are rotated about an axis substantially normal to the display surface, the cancellation of imperfection of the quarter waveplates 46 and 47 breaks down and the non-perfect nature of these plates becomes apparent. Figure 16 illustrates the extinction of light through the barrier regions 24 using this arrangement and for relative angular rotations of 0, 5, 10 and 15 degrees. Transmission below 1% for the majority of the visible spectrum can be achieved for angular displacements up to 10 degrees. Thus, an alignment tolerance of plus or minus 10 degrees can be achieved and is twice that which is available when the quarter waveplates 46 and 47 are omitted.

In order to improve the performance of the elements performing the rotation of polarisation when such elements are embodied as birefringent retarders, they may be fabricated as two or three layers of retarder of specific thicknesses and relative optic axis angles. Combinations of waveplates for broadband performance are disclosed in Proc. Ind. Acad. Sci, vol. 41, No. 4, section A, pp. 130, S. Pancharatnam "Achromatic Combinations of Birefringent Plates", 1955.

CLAIMS

1. A parallax barrier comprising: a polarisation modifying layer having aperture regions, for supplying light of a second polarisation when receiving light of a first polarisation, separated by barrier regions, for supplying light of a third polarisation different from the second polarisation when receiving light of the first polarisation; and a polariser selectively operable in a first mode to pass light of the second polarisation and to block light of the third polarisation and in a second mode to pass light of the second and third polarisations.

2. A barrier as claimed in Claim 1, in which the aperture regions comprise parallel elongate slit regions.

3. A barrier as claimed in Claim 1 or 2, in which the polariser is a uniform polariser.

4. A barrier as claimed in any one of the preceding claims, in which the third polarisation is orthogonal to the second polarisation.

5. A barrier as claimed in any one of the preceding claims, in which the first, second and third polarisations are linear polarisations.

6. A barrier as claimed in Claim 5, in which the aperture regions are arranged to rotate the polarisation of light and the barrier regions are arranged not to rotate the polarisation of light so that the third polarisation is the same as the first polarisation.

7. A barrier as claimed in Claim 6, in which the aperture regions comprise retarders.

8. A barrier as claimed in Claim 7, in which the aperture regions comprise half wave plates.

9. A barrier as claimed in Claim 6, in which the aperture regions comprise polarisation rotation guides.

10. A barrier as claimed in any one of the preceding claims, in which the polariser is removable from a light path through the polarisation modifying layer in the second mode.

11. A barrier as claimed in Claim 10, in which the polariser comprises glasses to be worn by an observer in the first mode.

12. A barrier as claimed in any one of Claims 1 to 9, in which the polariser comprises a polarising layer and a retarder layer which is switchable between a non-retarding mode and retarding mode providing a quarter wave of rotation.

13. A barrier as claimed in any one of Claims 1 to 9, in which the polariser comprises a polarising layer and a switchable diffuser having a diffusing depolarising mode and a non-diffusing non-depolarising mode.

14. A barrier as claimed in Claim 13, in which the diffuser is disposed between polarising layer and the polarisation modifying layer.

15. A barrier as claimed in Claim 13, in which the polarisation modifying layer is disposed between the polarising layer and the diffuser.

16. A barrier as claimed in any one of the preceding claims, comprising: a first quarter wave plate disposed between the polarisation modifying layer and the polariser and attached to the polarisation modifying layer; and a second quarter wave plate disposed between the first quarter wave plate and the polariser and attached to the polariser, the first and second quarter wave plates having substantially orthogonal optic axes.

17. A display comprising a barrier as claimed in any one of the preceding claims and a spatial light modulator for supplying light of the first polarisation to the polarisation modifying layer.

18. A display as claimed in Claim 17, in which the spatial light modulator is a light emissive device.

19. A display as claimed in Claim 17, in which the spatial light modulator provides selective attenuation of light and is associated with a light source.

20. A display as claimed in Claim 19, in which the spatial light modulator comprises a liquid crystal device.

21. A display comprising a barrier as claimed in any one of Claims 1 to 16, a light source for supplying light to the polariser, and a spatial light modulator having an input polariser for passing light from the aperture regions.

22. A display as claimed in Claim 21, in which the spatial light modulator comprises a liquid crystal device.

23. A display comprising: a light source selectively operable in a first mode for supplying light of a first polarisation and a second mode for supplying unpolarised light; a polarisation modifying layer having aperture regions, for supplying light of a second polarisation when receiving light of the first polarisation, separated by barrier regions, for supplying light of a third polarisation different from the second polarisation when receiving light of the first polarisation; and a spatial light modulator having an input polariser for passing light of the second polarisation and for blocking light of the third polarisation.

24. A display as claimed in Claim 23, in which the aperture regions comprise parallel elongate slit regions.

25. A display as claimed in Claims 23 or 24, in which the light source comprises a polarised light source operable in the first mode and an unpolarised light source operable in the second mode.

26. A display as claimed in Claim 25, in which the polarised light source comprises at least one first light emitting device arranged to supply light through a polariser to a first light guide.

27. A display as claimed in Claim 26, in which the unpolarised light source comprises at least one second light emitting device arranged to supply light to a second light guide and one of the first and second light guides is arranged to supply light through the other of the first and second light guides.

28. A display as claimed in Claim 23 or 24, in which the light source comprises at least one light emitting device, a light guide, and a polariser disposed in an optical path between the or each light emitting device and the light guide in the first mode and outside the optical path in the second mode.

29. A display comprising: a polarisation modifying layer having aperture regions, for supplying light of a second polarisation when receiving light of a first polarisation, separated by barrier regions, for supplying light of a third polarisation different from the second polarisation when receiving light of the first polarisation; a spatial light modulator having an input polariser for passing light of the second polarisation and for blocking light of the third polarisation; a light source; a mask having polarising regions, for supplying light of the first polarisation from the light source and non-polarising regions, for transmitting light from the light source; and a parallax optic cooperating with the mask to direct light from the polarising regions through the spatial light modulator to a first viewing region and to direct light from the non-polarising regions through the spatial light modulator to a second viewing region.

30. A display as claimed in Claim 29, in which the mask is movable relative to the parallax optic for moving the first and second viewing regions.

31. A display as claimed in Claim 29 or 30, in which the parallax optic comprises an array of parallax generating elements.

32. A display as claimed in any one of Claims 29 to 31, in which the aperture regions comprise parallel elongate slit regions.

33. A display as claimed in Claim 32 when dependent on Claim 31, in which each of the parallax generating elements is optically cylindrical with an axis substantially orthogonal to the slit regions.

34. A display as claimed in Claim 31 or 33, in which the array comprises a lenticular screen.

35. A display as claimed in Claim 31 or 33, in which the array comprises a parallax barrier.

36. A display as claimed in any one of Claims 29 to 35, in which the polarising and non-polarising regions comprise laterally extending strips.

37. A display as claimed in any one of Claims 29 to 36, in which the mask further comprises opaque regions at least partially separating the polarising regions from the non-polarising regions.

38. A display as claimed in any one of Claims 23 to 37, in which the third polarisation is orthogonal to the second polarisation.

39. A display as claimed in any one of Claims 23 to 38, in which the first, second and third polarisations are linear polarisations.

40. A display as claimed in Claim 39, in which the aperture regions are arranged to rotate the polarisation of light and the barrier regions are

arranged not to rotate the polarisation of light so that the third polarisation is the same as the first polarisation.

41. A display as claimed in Claim 40, in which the aperture regions comprise retarders.

42. A display as claimed in Claim 41, in which the aperture regions comprise half wave plates.

43. A display as claimed in Claim 40, in which the aperture regions comprise polarisation rotation guides.

The Patent Office

3b

Application No: GB 9713985.1
Claims searched: All

Examiner: Joe McCann
Date of search: 29 July 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H4F(FDD);G2J(JB7P,JX15)

Int Cl (Ed.6): H04N(13/00.13/02,13/04,15/00);G02B(27/22,27/26)

Other: Online: WPI, INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	US 5264964 (FARIS) - see column 5 lines 10 to 37 and figure 7b	1-5

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.